Effect of Uneven Rein Tension on the Kinematics of Unridden Western-discipline Trained Horses Moving at the Walk

Undergraduate Honors Thesis

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Sarah Kinsey Shaffer

Department of Mechanical Engineering

The Ohio State University

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Thesis Committee: Robert Siston, PhD, Advisor

Kimberly Cole, PhD

Abstract

Equine biomechanics as a discipline seeks to understand the role of horse-rider interactions and loading of musculoskeletal structures to help prevent injury and improve rehabilitation strategies for horses. However, most equine biomechanics research focuses on horses performing in English, rather than Western, disciplines. One principle taught in both styles of riding is the importance of "keeping the reins even," unless one is trying to alter a horse's movement. However, no research has been performed to evaluate how uneven rein tension affects equine kinematics. Therefore, the purpose of this project was to determine how uneven rein tension affects the stride length, stride velocity, and joint angles of unridden western-discipline trained horses moving at the walk. Because few programs are available for motion capture on horses, an additional goal was to create a passive-marker tracking program to capture these kinematic parameters. Rein tension was measured using small luggage scales placed on either side of a snaffle bit with the reins attached to a surcingle around the horse's heartgirth. To track motion, bony landmarks of eight joints were palpated and marked using white paste. Videos were recorded while the reins were positioned at five different tension settings. Kinematic parameters were then extracted using a custom-made MATLAB program. The differences in these parameters at the various tension settings were not statistically significant; however, previous research supports the angles and stride lengths observed in this study. Therefore, the developed passive-marker tracking program could be used to calculate joint angles and stride length with reasonable accuracy for equines or other large animals.

Acknowledgements

I would like to thank my parents, Dan and Sharon Shaffer, for their continued support in my education and all my equine related activities. I am exceedingly grateful that they have let me, and encouraged me to, take my horse across the US to various reining horse shows.

In addition, I would like to thank Dr. Robert Siston for encouraging me to combine my interests in engineering with my love of horses and for introducing me to biomechanics as a field of study. I would also like to thank Dr. Kimberly Cole for her help navigating the equine science side of this project. Finally, I would like to thank Autumn Rose Farm, in Dublin, OH, for allowing me to use some of their horses for this study.

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Chapter 1: Introduction

1.1 Horse Industry in America

With over 9 million horses in the United States, the horse industry has a direct economic impact of $39 billion and an indirect impact of over $102 billion annually [1]. In Ohio the horse industry has over a $2.2 billion impact on the economy yearly, with a majority of the horses being used for recreation, showing, and racing [2]. Of those main uses, racing and showing have the largest direct effect on the GDP. Additionally, according to Bloomberg Businessweek, following consumer electronics, the pet care industry in the fastest growing category in retail, with Americans spending on $41 billion dollars annually on their pets. As people are willing to spend more on their pets, the "quality gap" between human and companion animal services, food, and, most importantly, health care is starting to close [3]. While horses are legally considered livestock in the United States, as they are used more for recreation and showing, rather than work, owners appear to be willing to invest more in their equine companion's health care. However, compared to companion animals (e.g. dogs), relatively little research has been done on equine biomechanics. Among the studies done on equine biomechanics, most focus on horses trained in the English-disciplines, while little work has examined those trained in Western-disciplines [4]. It is important for the equine industry to have information available on both styles of riding because the equipment, training methods, movement styles, and breeds used vary dramatically. Also, horses being used for the different disciplines are prone to different injuries [5]. For example, elite evening horses have a much higher risk of superficial digital flexor tendon strain whereas, flat racing horses are more prone to carpus and pelvis injury [5]. A parallel to human athletics is that football linebackers are susceptible to concussions, but gymnasts are more likely to get a sprained ankle.

1.2 Review of Equine Biomechanics Research

Historically, equine biomechanics focused on classifying the main gaits of horses: the walk, the trot, the canter, and the gallop. However, by the early 1900s, these gaits had been fully classified. Due to a decline in the horse population during World War II, research halted until the 1960s when horses gained popularity as a sports and recreational animal. Today, equine biomechanics research focuses on studying the biomechanical loading of the equine musculoskeletal system and the effects of horse-rider interactions in the hopes of improving training techniques, monitoring performance, reducing injury, and improving rehabilitation methods [6].

Horse-rider interactions studies seek to understand the effects of human-imposed restrictions on equine movements. These studies range from looking at shoeing types to the effect of rider weight. Because this thesis looks at the effect of rein tension, horse-rider interaction studies focused on the effect of reins were reviewed. The effects of head and neck position, as well as rein type, on the movement of English-discipline horses have been extensively researched in Europe [6-8]. These studies found that elevated head positions reduce stride length and the flexion-extension motion of the back. Additionally, one study on the effect of rein type showed that rein type can affect fore- and hind-limb propulsion at the walk and trot and stride regularity at the walk [7]. However, no studies have investigated the direct effect of uneven rein length on horse motion in either the English or Western disciplines. It is important to understand how uneven rein length can affect horse motion because keeping “your reins even” is a fundamental principle riders are taught, regardless of discipline. Beginning riders are usually taught to always keep their reins even, but as a rider advances they learn that making the reins slightly uneven, in combination with other cues, can modify their mount's movement. Interestingly, no biomechanical studies have been done to see if uneven reins really do affect how a horse moves.

1.3 Focus of Thesis

The focus of this thesis is the development, testing, and validation of a passive-marker tracking program designed to determine the joint angles, stride length, and stride speed of western-trained horses moving at the walk. Additionally, the specific joint angles, stride length, and speed of one horse walking with various settings of uneven rein tension were analyzed for statistically significant changes. As previously mentioned, this project was motivated by the fact that there are currently no studies that have looked at the effect of uneven rein tension on the kinematics of Western-trained horses.

1.4 Overview of Thesis

This thesis contains five chapters. Chapter 2 gives a description of how the passive-marker tracking program was developed and validated. Chapter 3 discusses the tension measuring device and the animal testing plan. Chapter 4 gives a summary of the results of trials run on one animal and Chapter 5 provides a summary of this project and future applications. References and an Appendices are given at the end.

Chapter 2: Passive-Marker Tracking Program Development and Validation

2.1 Review of Gait Analysis Systems

In humans, kinematic gait analysis is performed using motion capture systems that track the movement of markers directly attached to the human body. These markers are placed on points of interest to the researchers, such as the spinal processes or leg joints, and the subject is then recorded performing the desired action. A computer program then extracts the coordinate location of the markers in each frame in order to build a 2-D or 3-D map of the subject's movement [8].

Active-marker motion capture systems use markers that emit light, whereas passive-marker systems use markers that reflect light [9]. Active markers are coded (i.e.- flash light in specific sequences) so that the software program can tell the markers apart. Passive markers cannot interact with a computer, as they are only capable of reflecting light from their surroundings. Therefore, additional software is needed to distinguish these markers during automated marker tracking. In traditional systems, these passive markers are often small, lightweight spheres or reflective tape that can be either directly attached to the subject's body or attached via a ridged mount [10]. An example of a typical active-marker motion capture system marker setting-up can be seen in Figure 1.

Figure 1: Active marker motion capture **[11]**

There are a several companies who offer software for gait analysis of horses, such as OnTrack Equine and Qualisys [12] [13]. OnTrack Equine can be used by veterinarians to help diagnose lameness; however, it is not able to do automated marker tracking. Due to this, it was undesirable for this project. Qualisys offers an active-marker tracking system for horses; however, it was too expensive to obtain a license for this project. Therefore a program was written to track passive markers and extract the relevant kinematic data based on the principles of programs used for classical gait analysis.

2.2 Equipment and Marker Material

A Sony HandyCam DCR-SR68 was used to record all video trials at a frame rate of 29.97 frames per second, limiting our sampling rate to 30Hz. The minimum sampling rate that allows positional fidelity to be maintained in human walking is 30 Hz; although higher sampling rates allow for better estimates [14]. However, the 30 Hz sampling rate was deemed acceptable for this study. Only one video camera was used, allowing for 2D analysis of joint angles, stride length, and velocity.

Due to the difficulty of attaching LEDs to a horse's body, it was decided to use passive-markers for the tracking program. Aerosol touch-up paint, non-toxic children's paint, circular stickers, and toothpaste were all tried as possible marker options. The white aerosol equine touch-up paint was difficult to confine to the necessary once inch diameter circle for the marker and was very difficult to remove if applied in the wrong location. The children's paint did not dry quickly enough and the stickers fell off after several strides. The toothpaste markers stayed in place much better than the aerosol paint, liquid paint, and stickers. Therefore, white Crest toothpaste was used to create one-inch diameter circular markers for the passive tracking program.

2.3 Overview of Developed Program

This project's equine gait analysis program was written in MATLAB R2012a and heavily utilizes the Image Processing and Signal Processing Toolboxes [15]. The code itself is contained in two M-files that call function files when necessary. The first M-file is used to extract the coordinate location of the markers, and second file is used to calculate joint angles, stride length, and forward velocity from the locations provided by the first file. A video, recorded at 29.97 fps, containing the trial to be analyzed is input into the first M-file. The video is then divided into its individual frames. The M-file then extracts the (x,y)-location of the center of a specified marker in each frame and writes those locations to an excel file. This M-file is run once for each marker. The second M-file then takes the (x,y)-locations from the excel file and calculates the necessary kinematic properties. An overview of this process can be seen in Figure 2.

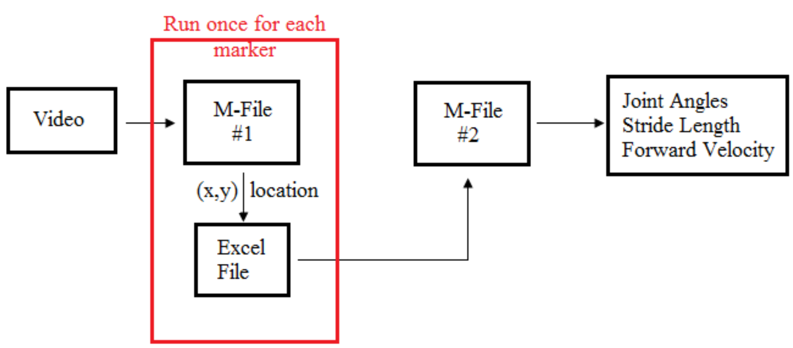

Figure 2: Overview of Program

2.4 Extracting Coordinates from Video Trial

The program is able to locate the center of a specified marker by manipulating the images using functions found within MATLAB's Image Processing Toolbox. For each video, the first 1-2 seconds of footage are taken of the background and therefore include information that remains mostly static over the course of the video. Because the video trials were recorded in a horse barn, the lighting varies slightly during the course of the trial. Therefore, the first step of image processing was to create a “mean background image” from the frames recorded of the background during the first 1-2 seconds, or 30-60 frames, of the trial. Once the mean background is constructed, the program begins processing the video frames that contain marker information.

Each frame from the recorded trial (not including background frames mentioned above), is processed with the same three steps: background subtraction, Gaussian filtering, and Hough transform. The first step, background subtraction, subtracts the pixel values in the mean background image from the individual video frame. This is done to create a new image that has less information for the computer to process when looking for circular markers. The second step is to apply a Gaussian low-pass filter to the image, this filter removes noise by smoothing sharp edges and makes the edges of the circular markers more clearly defined. The Gaussian filter is rotationally symmetric and has a (15 x 15) pixel size with a 1.5 standard deviation; this size was determined using trial-and-error. The third step applies a Hough Transform to the image to find circles of a particular radius; because the diameter of the markers were between 1 and 2 inches, translating to 2 to 7 pixels, that was the radii specified by the Hough Transform command. The imfindcircles() MATLAB command applies this transform and returns the (x,y)-coordinate of the circle’s center. If no circles are found using the Hough Transform, the program will ask the user to manually select a location for the center of the marker using their mouse. A flow chart of these three steps can be seen in Figure 3.

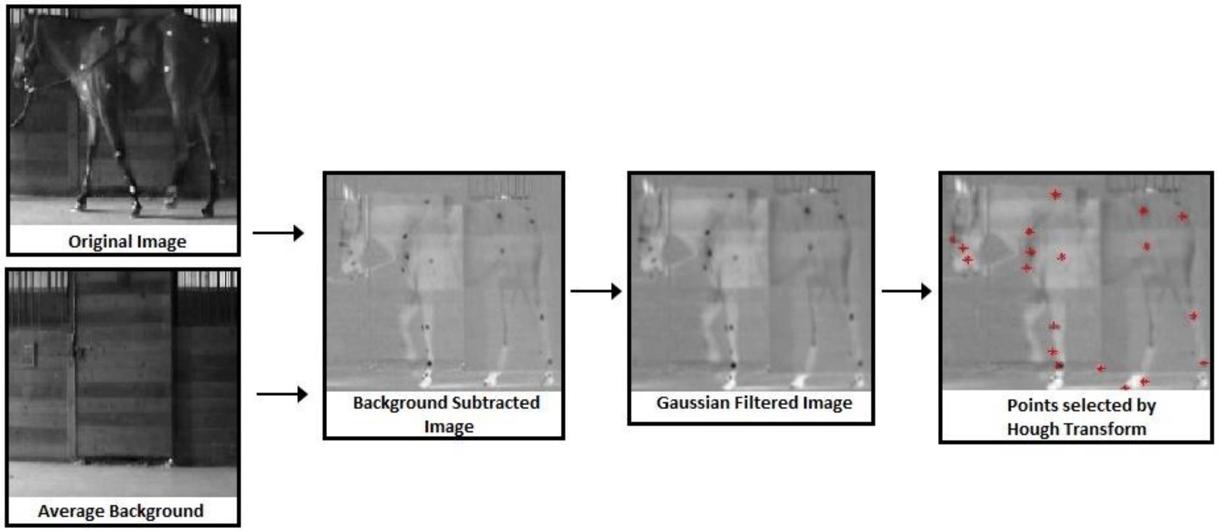

Figure 3: Image Processing Steps

Because passive markers were used, the computer cannot automatically tell the markers apart. Therefore, for the first video frame in the trial for a particular marker, the user inputs a guess as to the first location of the marker center by double clicking on the desired point. A nearest neighbor search then compares that guess to the circles found by the Hough Transform to determine a more accurate center location. If the image is not the first in the sequence, it uses a nearest neighbor search to find the (x,y)-point returned by the Hough Transform that is closest to the point selected in the previous frame.

Due to the frame rate, the distal limb markers occasionally appeared as two distinct circles during the swing phase. In these frames, the program finds the midpoint between the centers of these two circles and uses that as the marker center. An example of a frame where this “double marker” occurred can be found in Figure 4; the inset of Figure 4 shows the area around the front coronet band marker zoomed-in so that the “double marker” effect is visible.

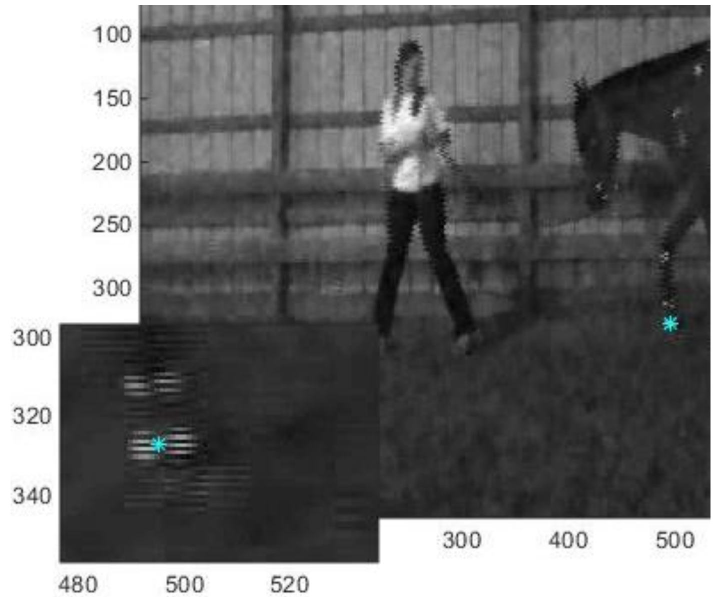

Figure 4: Double Marker on Front Cornet Band

Additionally, series of checks are run over each (x,y)-point selected by the nearest neighbor search to ensure that it actually is a good approximation of the marker's center. The first check makes sure that the distance between the current and previous point is approximately equal to the average of the distance between points in previous iterations. A second check makes sure that the radius of the circle found by the Hough Transform is approximately equal to the radii found in previous iterations. These checks protect against the program selecting incorrect (x,y)-points when the marker moves rapidly, such as during the swing phase of a limb. They also protect against the program selecting dark points on the wall or arena floor that occasionally appear due to the changing lighting conditions during the video trial.

If any of the checks fail, the program shows the users a zoomed-in image of the point and asks if it is acceptable. The user can then choose to respond "Yes," in which case the program will continue to the next video frame, or "No" in which case the program will allow the user to manually select a point. A flow-chart of this process can be seen in Figure 5**.** Figure 6 shows how a selected point, and the area zoomed-in around it, are displayed for the user.

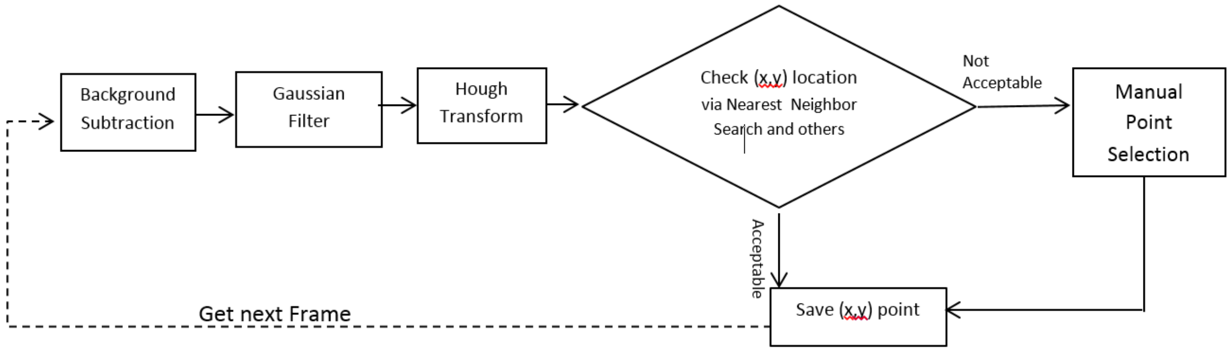

Figure 5: Flowchart of Passive-Tracking Program

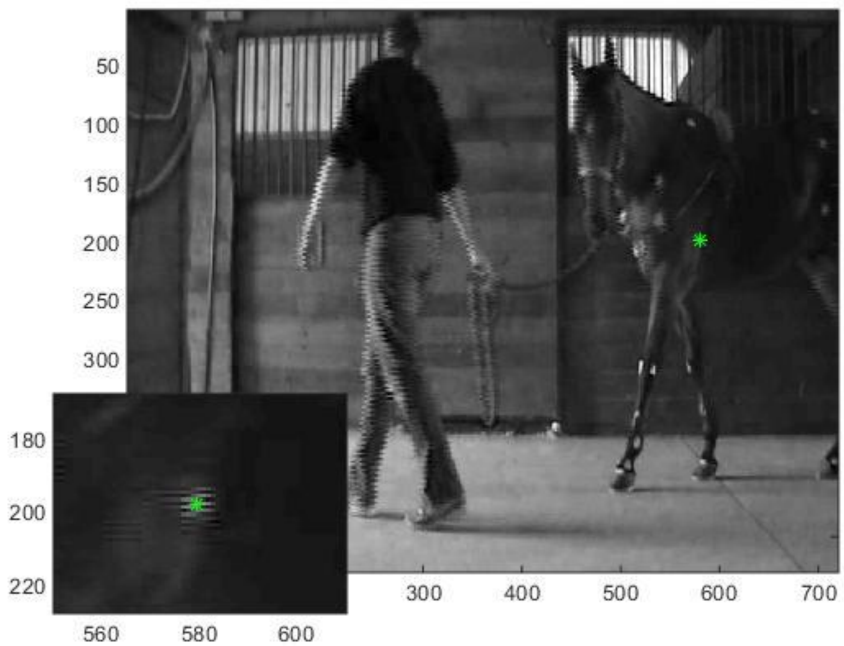

Figure 6: Point Selection

Once the program has processed all the frames of a video trial containing information about one marker, the set of (x,y)-points are written to an excel file. The program will then be run again until all markers have been tracked. Example of tracked data points for the knee and front fetlock markers, overlaid on the background, can be seen in Figure 7 and Figure 8.

Figure 7: Knee points for 50 frames

Figure 8: Fetlock points for 70 Frames

2.5 Data Filtering

The raw coordinate location data from the tracking program was run through a fourth order lowpass digital butterworth filter with a cutoff frequency of 6 Hz. Lowpass butterworth filters are commonly used to filter human gait with a cutoff frequency between 5-6 Hz for the walk [14]. Fast Fourier transforms performed on the data showed that there were frequency spikes below 6 Hz, so it was also used as the cutoff frequency for the equine gait data. A comparison of filtered and raw gait data can be found in Figure 9. Once the gait data was filtered, joint angles, stride length, and forward velocity could be determined.

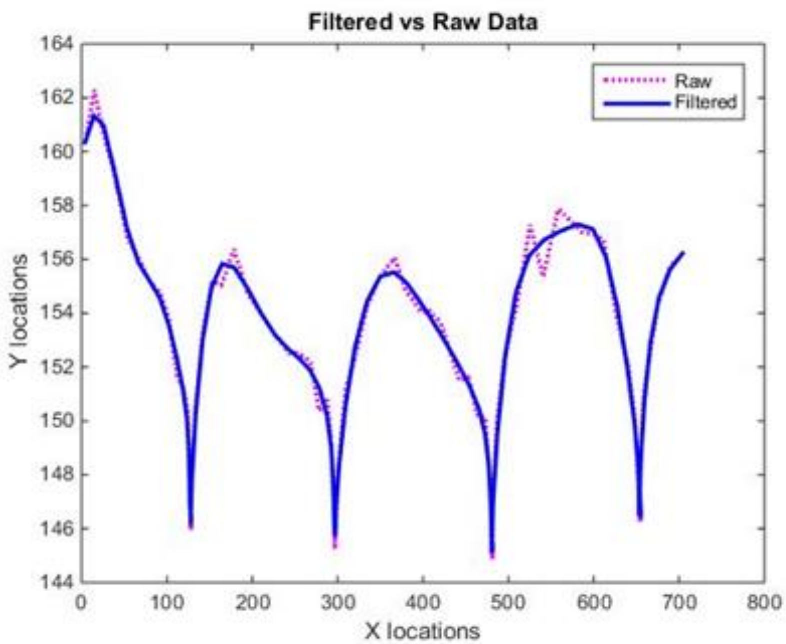

Figure 9: Raw and Filtered Gait Data

2.6 Stride Length and Velocity

In general, gait is defined as a complex and coordinated automatic rhythmic motion of the limbs that progresses the animal forward and a stride is defined as a complete cycle of limb motion during gait [16]. In horses, the walk is a four-beat gait in which there is only ever one limb suspended in the air. For the purposes of this thesis, the walk is divided into two phases based on the motion of the left forelimb (LF). If the LF is in contact with the ground, the horse is in the stance phase. If the LF is suspended in the air, it is in the swing phase. The transition between stance and swing occurs when the horse lifts its LF, or has toe-off (TO). The transition between swing and stance then follows when the horse replaces its LF on the ground, or has heel-strike (HS). The stance and swing phases are seen in Figure 10.

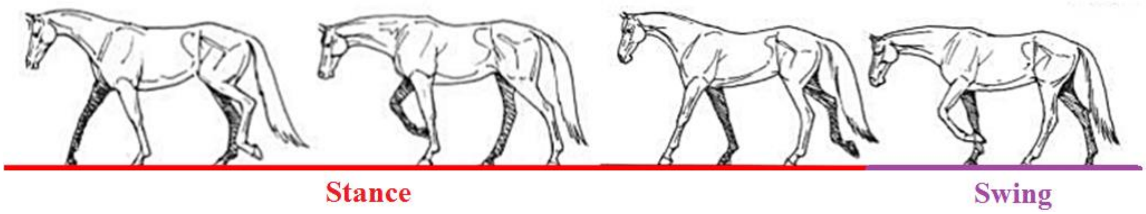

Figure 10: Stance vs Swing

The length of one stride is defined as the distance between “the successive hoof placements of the same limb” [16]. Therefore, it is calculated based on the horizontal distance between subsequent heel-strike points. To determine stride length, the user must first input which frames toe-off and heel-strike (HS) occurred for the LF. The program then plays a movie of the full trial showing the LF fetlock point at HS so that the user can visually check that they have input the correct frame numbers. If the frame numbers are wrong, the user then has a chance to re-enter them. An image of 4 HS points and the corresponding 3 stride distances can be found in Figure 11.

Figure 11: Heel Stride and Stride Length

The distance between the LF fetlock and LF knee points was measured when the video was recorded so that the actual stride length in inches could be determined. The program asks the user to input this measurement and then displays an image of the LF limb, asking the user to drag a measuring bar between the fetlock and knee points. The measuring tool itself is generated by MATLAB’s imdistline function. An example of this screen can be found in Figure 12.

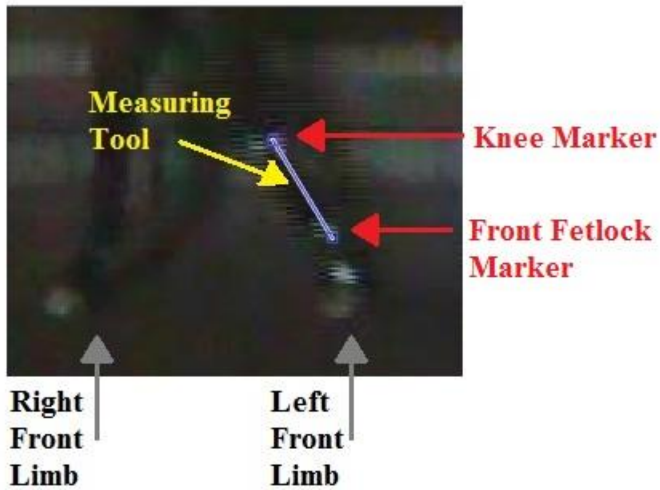

Figure 12: Measuring between the LF fetlock and knee markers

This ‘measuring’ process is done for all of the TO frames indicated by the user. The average pixel distance between the fetlock and knee point is then found and used with the known distance in inches to create a conversion ratio. This conversion ratio is then used to convert the stride length in pixels to inches.

Once the stride length is found in inches, the forward velocity can be calculated. The time for one stride is calculated by knowing which frame numbers consecutive HS occurred during and that there were 29.97 frames recorded per second. With the time per stride and stride length, the forward velocity can be found.

2.7 Joint Angles

Eight different joint angles were calculated: front fetlock, knee, elbow, shoulder, hip, stifle, hock, and rear fetlock. Each joint angle is defined by three points: a proximal, central, and distal point. The locations of these joint angles on a horse, and the markers used to describe them, can be found in Figure 13 and Table 1.

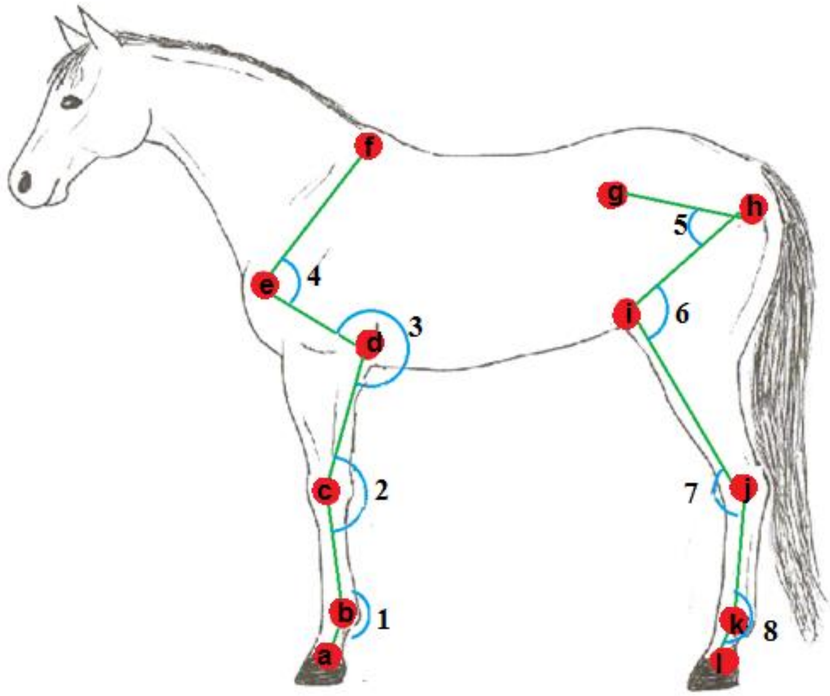

Figure 13: Joint Angles

Table 1: Identifying Joint Angles

Number	Joint Angle	Marker Letter
1	Front Fetlock	a,b,c
2	Knee	b,c,d
3	Elbow	c,d,e
4	Shoulder	d,e,f
5	Hip	g,h,i
6	Stifle	h,i,j
7	Hock	i,j,k
8	Rear Fetlock	j, k, l

All joint angles were calculated following the same three steps. First, four distances were calculated: the absolute distance between the central and proximal point and between the central and distal point, and the x-distance between the central and proximal and central and distal point. Second, two right triangles were constructed using the distances found in step one. The hypotenuse of one triangle runs from the proximal point to the central point and the hypotenuse of the second runs from the distal point to the central point. Third, the joint angle was calculated as a sum of the two interior angles. This process can be seen in Figure 14.

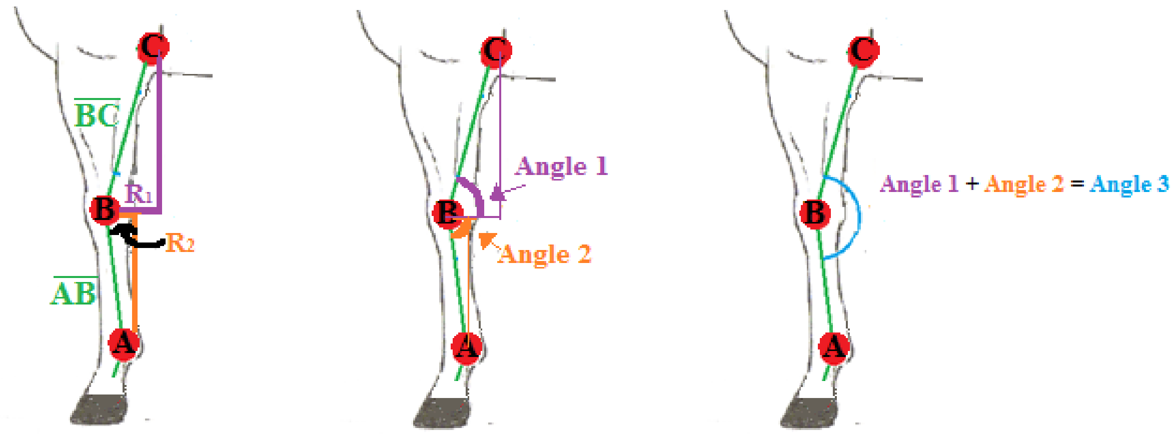

Figure 14: How to Find Joint Angles

An example image showing the calculated joint angles for one frame can be seen in Figure 15. The joint angles were calculated for each frame of the video trial.

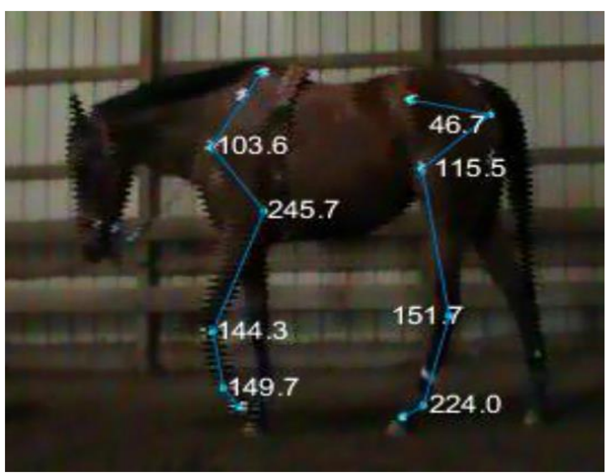

Figure 15: Joint Angles in one Video Frame

2.8 Code Validation Procedure

To check that the code determines the location of the markers with an acceptable degree of accuracy, tests were done using a goniometer to measure a known angle. A cardboard testing platform was used with a goniometer mounted on it, white paste markers were then placed at the ends and center of the goniometer. The top piece of cardboard was attached to the wall, while the bottom half was free to rotate. The bottom piece of cardboard was rotated to 0°, 30°, 60°, 90°, and 120° according to the goniometer, and videos were taken during these rotations. This setup can be seen in Figure 16.

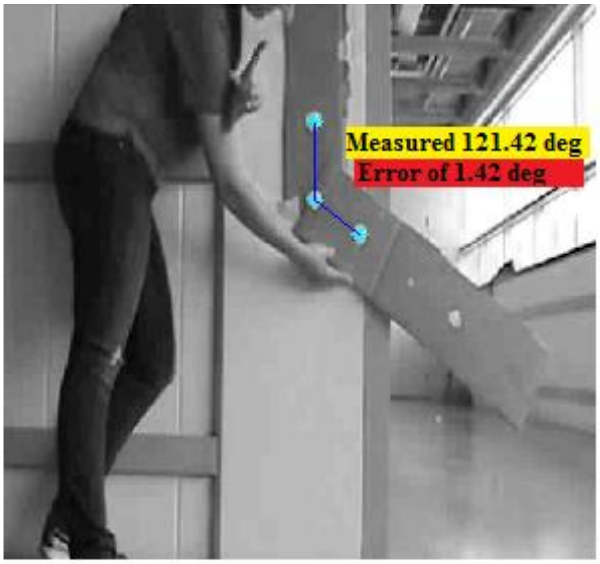

Figure 16: Testing Mount showing error at 120°

A total of four videos were taken in different lighting situations to mimic conditions at the barn, where lighting cannot be strictly controlled. These videos were then run through the tracking program, the resulting data was run through several butterworth filters and the angles were calculated. Different butterworth filters were used because the one used on the horse kinematic data had not been determined at the time accuracy was being tested.

The calculated angles were then compared to the goniometer angles. The program was determined to have ± 4° of accuracy. It was decided that ±4° was an acceptable degree of accuracy because smaller changes could probably not be felt by a rider or noticed by a judge.

Chapter 3: Testing Plan

3.1 Tension Settings

A study done on English trained horses, using a direct-pressure bit, showed that the tension, measured where the bit attaches to the reins, varied between 0 and 10 lbs at the walk [17]. Since a western-style leverage bit multiplies the force exerted at this attachment point, the maximum tension used for these trials was limited to 2 lbs. The horses were tested with the following tensions in the left and right reins: 0lb, 1lbs, and 2lbs. Table 2 shows the tensions settings used for trials in this study.

Table 2: Tension Settings

Left Rein	Right Rein
0 lbs	0 lbs
1 lbs	0 lbs
2 lbs	0 lbs
0 lbs	1 lbs
0 lbs	2 lbs

3.2 Tension Measuring Device

The tension measuring device consists of a surcingle, leather reins, western snaffle-bit with 4-inch shanks, curb chain, leather headstall, and two small luggage scales. One end of the luggage scale is attached to the shank of the bit and the luggage scale hook is attached a rein. An image of the device on a horse can be seen in Figure 17**.** An image of the luggage scale used in the device can be found in Figure 18 [18].

Figure 17: Tension Device on Horse

Figure 18: Luggage Scale

Leather reins and headstall were used for two reasons. First, they are commonly used in western disciplines. Second, leather is safer to use than nylon since it will break if a horse applies an extreme amount of stress to it, which can occur if they become frightened. A surcingle was used instead of a saddle because it can be adjusted easier to make sure the reins were being tied in a similar location on each animal. Additionally, a saddle would cover the wither and elbow area that needed to be marked during the trials. A snaffle-bit is used because it is jointed in the center, allowing it to move as tension is added. Additionally, the horses used in this study were used to being ridden in snaffles. An image of a typical snaffle bit can be seen in Figure 19 [19].

Figure 19: Western Snaffle Bit

A curb chain is commonly used in almost all western-style bridles and helps relieve pressure from the bit in the animal's mouth; therefore, it was also included in the bridle. The luggage scales were selected because they are small enough to attach to the shank of the bit and were able to be read at a resolution of 0.25 lbs; which is a smaller resolution than needed for this study. Also, they weighed 3.2 oz, which was light enough to not add extra stress on the horse [18]. The horse also wore a halter underneath the bridle. A lead-rope was then be attached to the halter, so the horse could be lead during the trials without pulling on the reins.

3.3 Horse Selection & Preparation

Three American Quarter Horses between the ages of 5 and 12, two geldings and one mare, were used in this study. The horses are trained in the western disciplines of horsemanship or reining. Additionally, their conformation was similar. The horses were lesson horses living at Autumn Rose Farm, in Dublin, OH; so their living conditions, soundness levels, diets, and work amounts were similar. All three horses were used during program and tension device development and the mare was used for the trials that were analyzed.

Since the gait tracking program requires the horses to have white dots placed on their bodies, the animals selected were either bay or chestnut (i.e. shades of brown) providing the necessary contrast between the markers and the horses' coat. If the horses had white markings on their distal limbs, a pair of dark brown panty-hose with the toe cut off was put over the marking. The hose is tight enough that it did not slide down the animal's leg during the trials, but was not so tight as to bother the animal.

In addition, all of the horses were acclimated to the tension rig for at least an hour the day before they were filmed, and for 15 minutes on the day they were filmed. Additionally, the procedures used to video these animals, and the tension-device itself, were approved by The Ohio State University's Institutional Animal Care and Use Committee.

3.4 Marker Location

Twelve markers were placed on each side of the horse's body over major skeletal landmarks. Figure 20 shows the marker location over an image of an equine skeleton and Figure 21 shows marker location on a horse being tested; Table 3 lists the skeletal landmarks the numbered markers indicate.

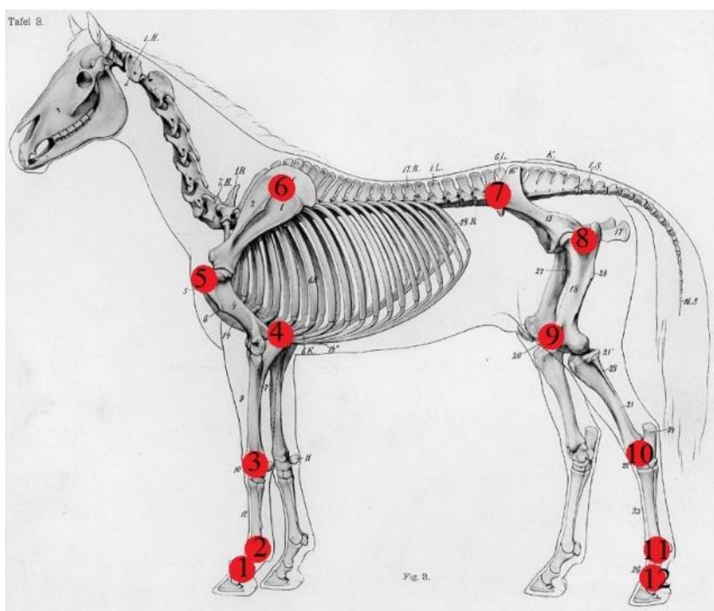

Figure 20: Marker location on Skeleton **[20]**

Table 3: Skeletal Landmarks indicated by markers

Marker Number	Joint Location
1	Front Fetlock
2	Front Fetlock
3	Knee Joint
4	Elbow
5	Point of Shoulder
6	Withers
7	Point of Hip
8	Hip
9	Stifle
10	Hock
11	Rear Fetlock
12	Rear Fetlock

Figure 21: Marker location on horse

3.5 Data Collection

On video collection day, the horse was put into the tension device and hand-walked around the arena for 15 minutes at various tension settings. Then, the tension device was removed and the horse was tied while the paste marker were applied. The distance between the markers were recorded in case one was disturbed during filming and for use in determining stride length. The horse stood for about 10 minutes while the arena was prepared, this allowed the paste to dry. One individual remained with the horse to ensure the paste markers were not smeared.

To prepare the arena, the area where the trials occurred was raked to smooth the sand arena footing. A three foot tall rigid platform for the video camera was dug into the arena about

20 feet from the midline of the path where the animal was to be walked. This platform allowed the camera to remain rigid during the trials, and the distance the camera was placed allowed the horse to complete at least three strides within the camera's field of view. This set-up is illustrated in Figure 22. One person ran the camera, while another walked the horse in a straight line.

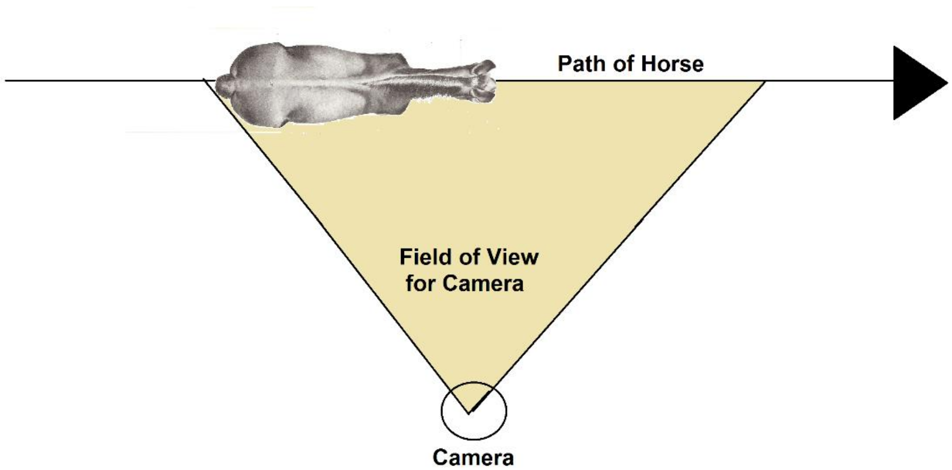

Figure 22: Camera Set-Up

Three video trials were recorded for the left side and right sides of the horse's body at each tension setting. This amounted to a total of 30 video trials.

3.6 Data Analysis

A general linear regression was run over 35 uncontrolled variables consisting of the kinematic parameters pulled from the video trials at each of the five tension settings. Three of these variables were stride length, stride time, and the ratio between time of swing and time of stance phase. Four variables were determined for each joint angle: the minimum angle during stance, the minimum angle during swing, the maximum angle during stance, and the maximum angle during swing. These four parameters, taken for all eight joint angles, make-up the final 32 uncontrolled variables. These 35 kinematic parameters were entered for each complete stride data was collected for; this amounted to between six and nine strides per tension setting, or between 30-45 strides total. A summary of the average values found for each parameter at the five different tension settings can be found in Tables A1-A9.

The linear regression determined if the mean of each uncontrolled variable, grouped by the tension setting, were different. A p-value smaller than 0.05 indicated that rein tension settings could be used to predict that variable; if the p-value was greater than 0.05 the rein tension setting should not be used as a predictor. The R^2 value for the results was also determined to ensure that the response could be explained by tension setting. The R^2 value is the percentage of response variable variation explained by its relationship to the rein tension settings [21]. As the R^2 value increases, the better the regression model fits the data. However, the standard error of the regression (S-value) was also determined. The S-value helps explain how the precise the data fit is (i.e. – smaller S-values indicate data point are closer to the fitted line) [22]. The p-values, R^2 values, and S-values for each uncontrolled variable are also found in Tables A1-A9.

Chapter 4: Results

4.1 Stride Length and Speed

Stride length and stride velocity were determined from trials taken of the left sagittal plane; three trials were taken at each tension setting. Each video trial contained, a minimum of two complete strides; therefore, between six and nine strides were available to be analyzed at for each tension setting. No statistically significant changes in stride length ($p = 0.7$) were seen at the different tension settings. However, the horse took slightly longer strides when there was no tension in either rein, moving at 3.7 ft/s. Additionally, uneven rein tension did not affect stride time, and therefore, did not affect stride velocity ($p = 0.37$). Table 4 gives the average stride length, time, and velocity at the five different tension settings.

Table 4: Stride Length and Time, calculated from Left Sagittal Plane

	2R0L	1R0L	0R0L	0R1L	0R2L
Stride Length (ft)	3.65	3.67	3.71	3.50	3.68
Stride Time (s)	1.41	1.35	1.37	1.37	1.45
Stride Velocity (ft/s)	2.58	2.72	2.71	2.55	2.53

In addition, the ratio of the time spent in the swing phase, as compared to the stance phase, was also investigated. However, there were also no statistically significant differences among the ratios at the various tension settings ($p = 0.75$). This swing-to-stance ratio stayed around 0.55 for all tension settings, meaning that the swing phase was a little bit over half of the time taken during stance. These values are shown in Table 5.

Table 5: Ratio Swing Phase to Stance Phase for Left Sagittal Plane

	2R0L	1R0L	0R0L	0R1L	0R2L
Ratio Swing/Stance (s/s)	0.56	0.56	0.52	0.54	0.53

4.2 Joint Angles

Joint angles were also calculated for video trials taken of the left sagittal plane. Joint angles for every complete stride in the video trial were calculated and used when determining correlations between rein tension and angle. Therefore, just as for stride length and velocity, joint angles were calculated for six to nine full strides at each tension setting. The eight joint angles calculated are: front fetlock, knee, elbow, shoulder, hip, stifle, hock, and rear fetlock. They are described in greater detail in Section 2.7.

In order to gain a better understanding of how joint angles may have been affected by uneven rein tension the maximum swing angle, maximum stance angle, minimum swing angle, and minimum stance angle were found for every angle during all recorded strides. The average minimum and maximum angles were then taken for each tension setting. A full listing of these joint angles can be found in Appendix A.

There were five angles where a small p-value ($p<0.05$) indicated that it could be predicted by the rein tension setting, as seen in Table 6. However, for the knee, shoulder, and hock the R^2 values for these angles were low (less than 70%), indicating the regression model did not fit the data and these correlations were not strongly supported.

Table 6: Joint angles with low p-values

	P-Value	R^2 Value	S-Value
Minimum swing angle for knee	0.004	62.23	1.82
Minimum swing angle for shoulder	0.002	69.16	2.06
Maximum stance angle for hock	0.023	50.93	1.42
Minimum swing angle for rear fetlock	0.000	24.39	8.10
Maximum stance angle for rear fetlock	0.000	87.12	2.08

The p-values were extremely low for the maximum stance and minimum swing angles of the rear fetlock. The groupings of tension settings returned by the regression model for the minimum swing angle of the rear fetlock did not make physical sense; this is confirmed by the low R^2 value (24%) and high S-value (8.10). Given that the rear fetlock marker was one of the distal limb points where the "double marker" phenomenon occurred during the swing phase, as explained in Section 2.4, it makes sense that these data were not as accurate as that collected for the other markers. However, the groupings for the maximum stance fetlock angle did make sense as it was divided groups based on if there was any tension in the left rein, any tension in the right rein, or no tension in either rein.   This indicates that the maximum stance angle for the rear fetlock is affected by the uneven rein tension settings; but, data needs to be collected for more than one horse before this conclusion can be confirmed.

Therefore, none of the calculated joint angles were shown to be dependent upon the rein tension setting. This lack of dependence on rein tension is illustrated in Figure 23 and Figure 24.

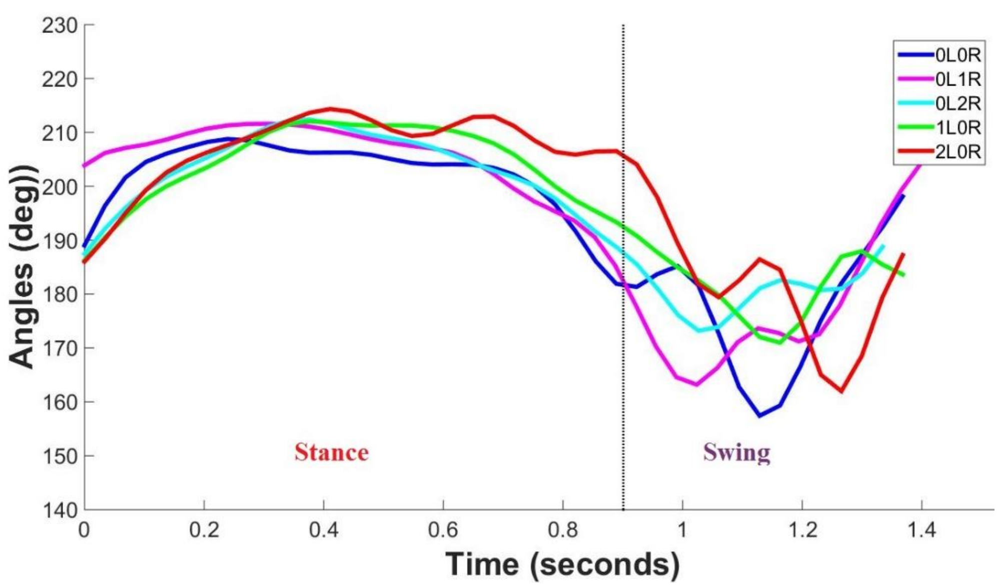

Figure 23: Left Front Fetlock Angles at All Tension Settings

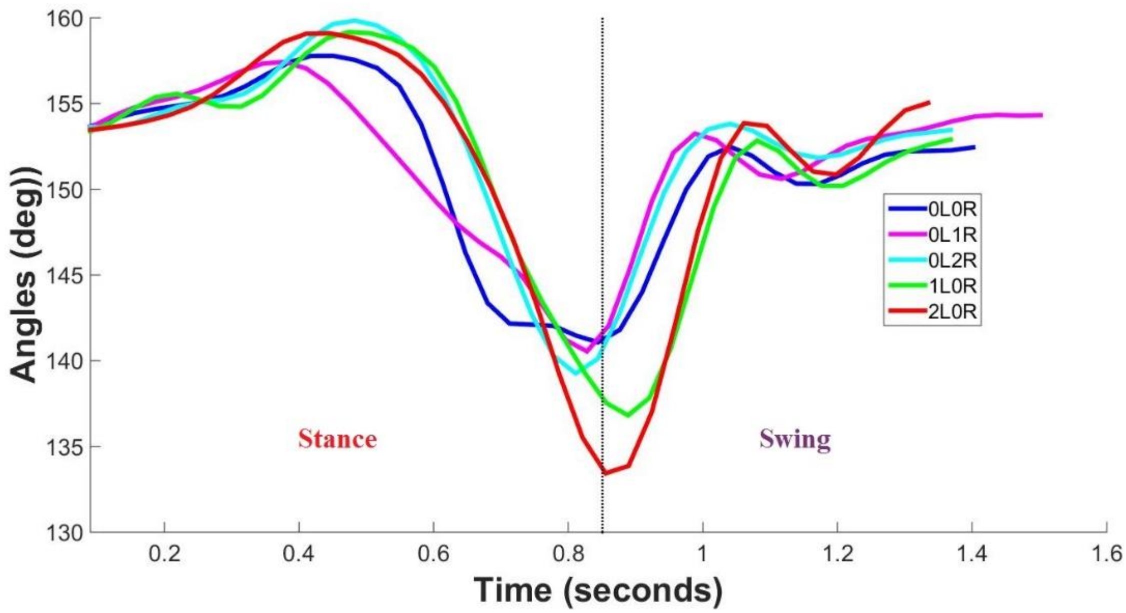

Figure 24: Left Hock Angles at All Tension Settings

Even though the individual joint angles did not experience any differences at the various tension settings; general trends were seen for the angles of the fore- and hind limb swing and stance phases. For the forelimb, larger angle ranges were seen for the front fetlock, knee, and elbow angles during the swing phase. However, the shoulder angle remained relatively constant, around 100^{o}, during the both phases. This trend held across all five tension settings; Figure 25 shows the forelimb angles during 2.5 strides when there was no tension in either rein. Additionally, the forelimb angle ranges during the stance and swing phases, for all tension settings, is given in Table 7.

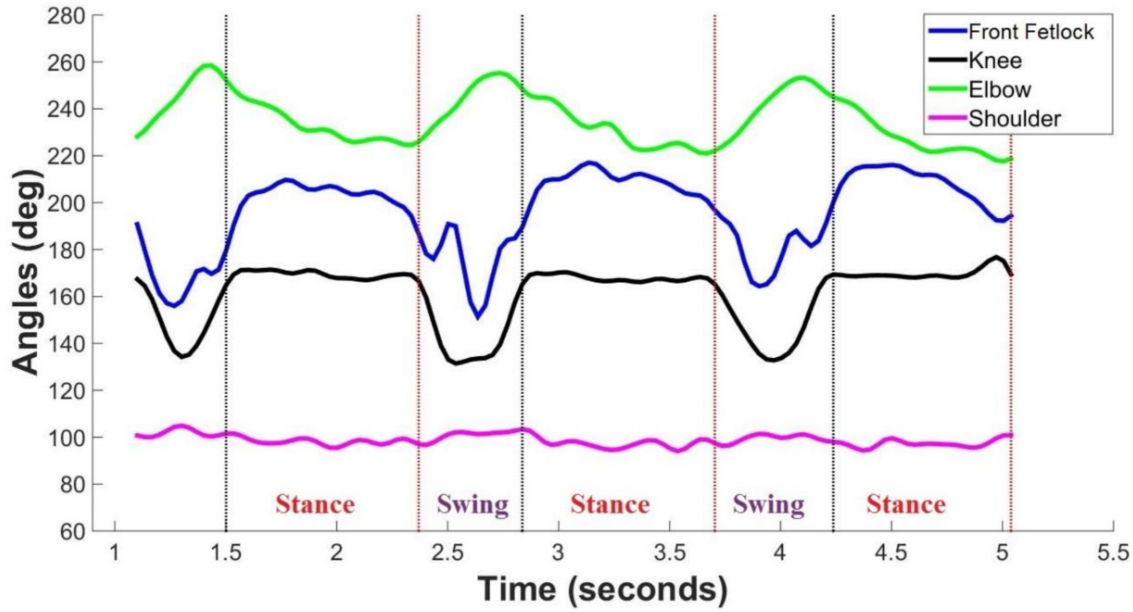

Figure 25: Front End Joint Angles from left sagittal plane with no tension in either rein

Table 7: Average Forelimb Angle Ranges for Left Sagittal Plane (min, max)

	Swing Phase	Stance Phase
Front Fetlock (degrees)	(162 ± 5, 196 ± 2)	(190 ± 2, 213 ± 2)
Knee (degrees)	(132 ±3, 168 ±1.5)	(162 ±1.5, 173 ± 1)
Elbow	(224 ± 2, 254 ±2)	(219 ± 2, 245 ±1.5)
Shoulder	(100 ±4, 104 ±2)	(95 ± 1, 105 ±1)

For the hind limb, the rear fetlock, hock, and stifle angles exhibited larger ranges during the stance phase, rather than the swing phase. Similar to the shoulder angle in the forelimb, the hip angle remained relatively constant during both phases. Once again, this trend held across all five tension settings; it can be seen in Figure 26. The average hind limb angle ranges are given in Table 8.

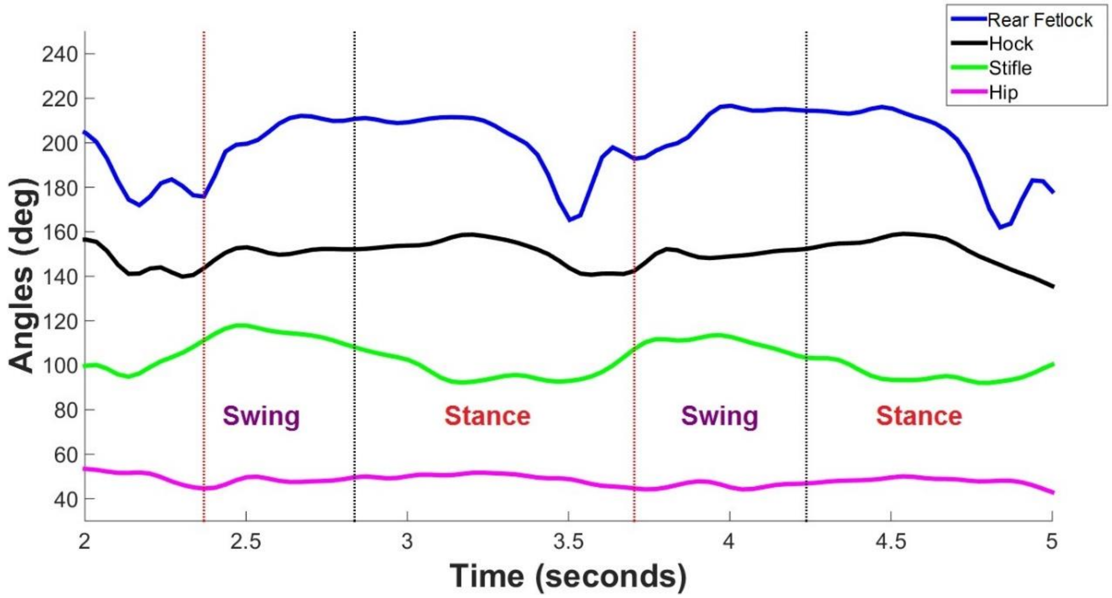

Figure 26: Hind End Angle Ranges in Left Sagittal Plane with no tension in either rein

Table 8: Average Hind Limb Angle Ranges for Left Sagittal Plane (Min, Max)

	Swing	Stance
Rear Fetlock (deg)	(190 ± 5, 220 ± 5)	(165 ± 3, 220 ±5)
Hock (deg)	(145 ± 6, 155 ± 6)	(134 ± 2, 159 ± 1)
Stifle (deg)	(107 ± 1, 116 ± 1)	(92 ± 0.5, 108 ± 1)
Hip (deg)	(45 ± 1, 49 ± 2)	(43 ± 1, 52 ± 1)

Chapter 5: Conclusions and Future Applications

5.1 Comparison of Results to Previous Work

Since no significant differences were seen between the measured kinematic parameters and the rein tension settings, additional literature was reviewed to check that the passive-marker tracking program was correctly calculating the parameters.

According to previous studies done on dressage horses, the average stride distance at the walk is between 1.2-1.8 m, or 4.9 to 5.9 ft [16]. The large range is stride length is dependent on if the horse was moving at a collected, medium, or extended walk; at an extended walk, the horse is trained to lengthen its stride while still maintaining a 4-beat walk gait. While these stride lengths are between 20-40% larger than the average found in this study, the difference between those data and mine can be explained because dressage horses are typically European Warmbloods breeds which are an average of 4-5 inches than the American Quarter Horse (QH) used in this study [23]. Therefore, the stride lengths found by the program are reasonable when compared to results published in this study.

Verification of the program's calculated joint angles was possible for the front fetlock, shoulder, knee, and hock joints based on information found in previous research. One study reported a minimum front fetlock joint angle for Warmblood horses moving at the walk of 136^{o}± 6.44 [24]. This is 17% smaller than the minimum angle ranges found for the front fetlock in this study, which were 164^{o} ± 5. However, the distal and proximal joint markers were located in different locations than those in this study. Their distal marker is in the center of the animal's hoof on the sagittal plane, while ours was in the cornet band; their proximal marker was slightly below the knee joint, whereas ours was on the center of the knee joint. [24] The difference in marker placement could account for the difference in reported angles.

A previous study showed that range of joint angles in the sagittal plane is dependent upon horse breed. They measured shoulder angles for Arabians at the walk between $120.7^{\circ} \pm 6.5$ and $103.1^{\circ} \pm 6.1$ [25]; the shoulder angles reported for this study were between 95° and 100°. However, their proximal marker was placed at the tuber spina scapulae and ours was placed at the withers; this difference in marker placement, along with breed, could be responsible for the difference in shoulder angle ranges. This study also reported a knee angle range of $186.7^{\circ} \pm 2.9$ to $109.7^{\circ} \pm 7.0$ for Arabian horses [25]; this range is slightly wider than ours, $132^{\circ} \pm 3$ to $173^{\circ} \pm 1$. Their marker placement was nearly the same as ours, but this difference could be accounted for by breed variation [25]. Unlike Quarter Horses, a stock-type animal bred to have little knee action, Arabian horses are bred for more knee action – meaning they have increased knee flexion as they move [26].

Finally, in another study performed looking at the effects of heel elevation on hock angle at the walk, the reported range of hock angle was 155-115° during one stride [27]. This is close to the range reported in this study of 155 – 134°; in addition, the curves traced by the hock angle during one stride have a similar shape, as seen in Figure 27.

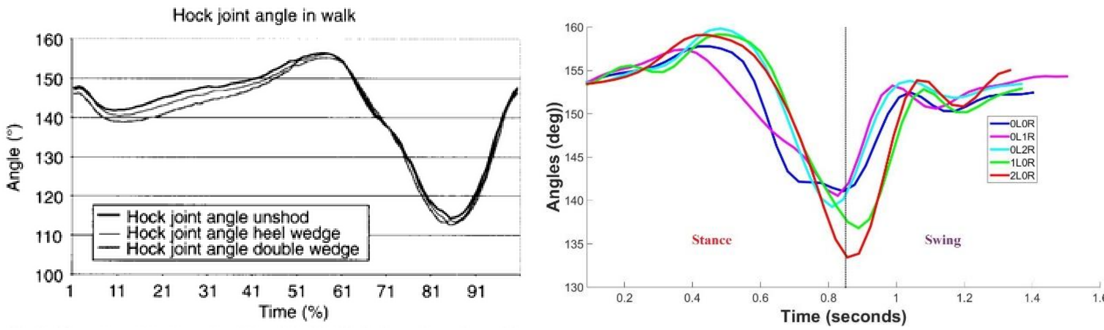

Figure 27: Reported Hock Angles **[27]**

Therefore, supporting research shows that the developed passive-marker tracking program works with a reasonable level of accuracy. It could be used for other studies investigating equine, or other large animal, kinematics.

5.2 Suggested Improvements and Future Possibilities

There are several possible reasons why no statistically significant links between the uneven rein tension settings tested in this study and the animal's stride length, stride velocity, and/or joint angles were seen. First, only one subject's kinematic data was analyzed. It is possible that if more horses had been evaluated, trends would have been seen. Second, the program was only accurate within 4°, so smaller changes may not have been noticed. However, if the angle changes were on that small of scale it would be questionable if the changes actually had a significant impact on the motion felt by the rider or viewed by a judge. Additionally, they may have been distortion of the images at the edges of the video camera's field of view that could have skewed the stride length calculations. Also, a higher frame rate camera would improve the accuracy of the angles that require the use of the distal limb markers.

The differences in rein tension at the various settings were large enough to change the horse's head carriage. At 0lbs in both reins, the horses would carry their head and neck directly in front of them. With 2lbs one rein and 0lbs in the other, the horse would bend its neck towards the direction of with the 2lbs of tension. Therefore, since the tension differences were great enough to affect head carriage, other problems with the experimental design could have caused no difference to be seen in the kinematic parameters as rein tension was changed. First, the reins were tied to the surcingle about three inches below the horse's withers. Most western riders will keep their hands, and thus the ends of the reins, above their mount's withers. This change in rein position could have influenced the animal's motion. Second, all angles analyzed in this study were in the left sagittal plane. If angles in the frontal or dorsal plane had been chosen, it is possible changes would have been seen. Finally, the trials were recorded as the horses were walking over sand, which is a typical arena footing. However, sand allows for hoof slide and footing deformation as the horse walks. If the trials had been recorded on concrete, which does not allow for significant ground deformation, changes in joint angles may have been more easily noticed.

Even with the possible experimental design problems, the passive-marker tracking program could be used in a future study as it has an acceptable degree of accuracy. However, in a future study, the discussed experimental design issues should be addressed. For example, the reins could be tied in a location to better mimic where reins are actually held by a rider or angles in a different plane of the horse's body could be chosen to analyze. In addition, the tracking program could be used to evaluate gait in other large animals.

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Appendix A: Determined Kinematic Parameters for Left Sagittal Plane

Table A1: Front Fetlock Angles

	2R0L	1R0L	0R0L	0R1L	0R2L	P- Value	R^2 value (%)	S-value
Min Swing Angle (deg)	167.6	161.2	160.5	167.2	155.7	0.060	43.30	5.37
Max Swing Angle (deg)	196.0	194.9	194.4	197.7	198.9	0.573	19.61	3.49
Min Stance Angle (deg)	191.9	192.1	191.0	188.3	188.2	0.820	9.81	5.61
Max Stance Angle (deg)	212.4	216.8	212.6	214.2	212.4	0.481	16.69	3.93

Table A2: Knee Angles

	2R0L	1R0L	0R0L	0R1L	0R2L	P-Values	R^2 value (%)	S-value
Min Swing Angle (deg)	135.3	132.0	132.7	135.0	128.3	0.004	62.23	1.82
Max Swing Angle (deg)	168.1	170.4	166.8	167.7	170.1	0.135	35.60	2.27
Min Stance Angle (deg)	161.2	161.6	162.6	162.4	165.4	0.711	12.52	3.38
Max Stance Angle (deg)	172.1	172.8	172.8	174.0	174.0	0.552	17.31	1.64

Table A3: Elbow Angles

	2R0L	1R0L	0R0L	0R1L	0R2L	P-Values	R^2 value (%)	S-value
Min Swing Angle (deg)	226.8	224.1	226.7	222.2	223.0	0.050	47.00	2.40
Max Swing Angle (deg)	256.5	250.9	255.3	253.0	254.5	0.128	38.05	2.74
Min Stance Angle (deg)	220.4	216.8	221.8	216.8	220.8	0.191	33.60	3.53
Max Stance Angle (deg)	246.7	244.1	248.1	246.2	244.7	0.169	35.02	2.28

Table A4: Shoulder Angles

	2R0L	1R0L	0R0L	0R1L	0R2L	P-Value	R^2 value (%)	S-value
Min Swing Angle (deg)	100.0	97.8	98.1	99.2	107.0	0.002	69.16	2.06
Max Swing Angle (deg)	105.3	104.4	103.6	107.1	100.4	0.174	34.66	3.02
Min Stance Angle (deg)	95.5	96.9	94.6	96.6	96.3	0.163	35.42	1.43
Max Stance Angle (deg)	103.4	105.5	102.7	103.7	105.1	0.657	15.02	2.82

Table A5: Hip Angles

	2R0L	1R0L	0R0L	0R1L	0R2L	P-value	R^2 value (%)	S-value
Min Swing Angle (deg)	46.2	43.5	47.0	44.4	45.4	0.628	15.01	3.49
Max Swing Angle (deg)	50.4	47.9	50.4	46.6	50.0	0.422	21.60	2.20
Min Stance Angle (deg)	43.2	43.1	44.0	42.4	44.8	0.571	16.75	1.84
Max Stance Angle (deg)	53.9	50.8	52.8	52.2	53.9	0.628	15.01	2.75

Table A6: Stifle Angles

	2R0L	1R0L	0R0L	0R1L	0R2L	P-value	R^2 value (%)	S-value
Min Swing Angle (deg)	108.7	106.0	108.2	107.4	106.8	0.866	7.65	3.75
Max Swing Angle (deg)	117.7	115.5	114.8	115.2	117.2	0.242	29.05	2.14
Min Stance Angle (deg)	92.7	93.2	92.7	92.4	92.1	0.986	2.21	2.23
Max Stance Angle (deg)	108.7	107.5	108.7	108.3	109.7	0.971	3.32	3.51

Table A7: Hock Angles

	2R0L	1R0L	0R0L	0R1L	0R2L	P-value	R^2 value (%)	S-value
Min Swing Angle (deg)	155.7	153.3	153.2	154.8	155.6	0.213	23.64	5.75
Max Swing Angle (deg)	147.8	155.4	142.7	144.1	138.0	0.367	30.75	1.87
Min Stance Angle (deg)	137.1	136.3	133.7	130.2	134.7	0.311	25.91	4.81
Max Stance Angle (deg)	159.6	159.3	157.0	160.2	159.6	0.023	50.93	1.42

Table A8: Rear Fetlock Angles

	2R0L	1R0L	0R0L	0R1L	0R2L	P-value	R^2 value (%)	S-value
Min Swing Angle (deg)	220.0	218.6	213.7	225.4	227.7	0.000	24.39	8.10
Max Swing Angle (deg)	196.0	191.4	188.5	194.1	183.3	0.348	88.25	2.06
Min Stance Angle (deg)	166.2	163.5	168.4	161.7	169.3	0.785	10.29	9.27
Max Stance Angle (deg)	220.0	212.9	218.0	223.5	227.1	0.000	87.12	2.08

Table A9: Stride Length, Stride Time, and Stance-Swing Ratio

	2R0L	1R0L	0R0L	0R1L	0R2L	P-Value	R^2 value (%)	S-value
Stride Length (ft)	3.65	3.67	3.71	3.50	3.68	0.785	10.27	0.25
Stride Time (s)	1.41	1.35	1.37	1.37	1.45	0.375	23.37	0.06
Ratio Swing/Stance	0.56	0.56	0.52	0.54	0.53	0.750	11.35	0.05

Appendix B: Passive-Marker Tracking Program Contact Information

If you would like access to the passive-marker tracking program that was developed for this project, please contact the author, Sarah Shaffer at shaffer.377@gmail.com, or her primary advisor, Dr. Robert Siston.